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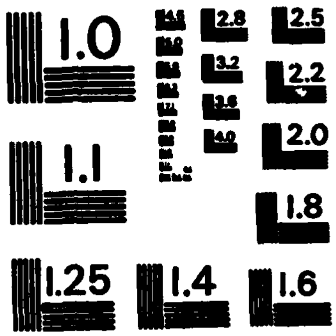

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AN OPERATIONAL HYGIENE STUDY FOR OZONE IN THE CABIN OF THE CANADIAN FORCES (CC137) BOEING 707 AIRCRAFT

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AN OPERATIONAL HYGIENE STUDY FOR OZONE IN THE CABIN OF THE CANADIAN FORCES (CC137) BOEING 707 AIRCRAFT

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DEPARTMENT OF NATIONAL DEFENCE - CANADA

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ABSTRACT

A study was carried out to determine the concentration of ozone in the cabin of the Boeing 707 (CC137) at altitude on a cross-Canada flight during a seasonal period of high atmospheric ozone. An ozone monitor manufactured by Columbia Scientific Industries (CSI), Austin, Texas was used to measure O_3 levels during the study. Prior to actual flight monitoring the analytical measuring equipment was calibrated at ground level and under simulated altitude conditions. Since ideal gas law corrections were not applicable at altitude it was necessary to prepare a correction factor for the CSI ozone meter under hypobaric conditions. In the flight trials, the maximum O_3 value obtained during the westerly segment of the flight at an altitude of 39,000 feet, was 135 parts per billion (ppb) and 106 ppb on the return easterly portion of the flight. These values slightly exceed the Threshold Limit Value (TLV) for ozone of 100 ppb. However, they are below the Short Term Exposure Limit (STEL) of 300 ppb. During a similar time period, Atmospheric Environment Services (AES), Environment Canada, measured an ozone concentration of 1670 ppb in the atmosphere at an altitude of 39,370 feet in the Edmonton, Alberta area. A comparison of the maximum cabin concentration obtained during this study with that found externally by AES indicates that the engines of the Boeing 707 were removing greater than 90% of the atmospheric ozone prior to its entry into the aircraft cabin. The findings of this study indicate that ancillary ozone removing equipment need not be added to the aircraft.

INTRODUCTION

Objective

This study was undertaken during the month of February, 1982 at the request of Director of Air Operations, Training and Nuclear Weapons (DAOTNW) and Director of Preventive Medicine (DPM) to determine ozone levels in the cabin of the Boeing 707 at normal flight altitudes on cross Canada flights. Based on these findings, a decision could be reached, by the sponsor, as to whether convertors or filters would be required to assist in the further destruction of ozone entering the aircraft cabin. As well, ozone levels obtained would determine if crew and passengers were being exposed to levels in excess of current occupational health standards.

OZONE - Biological Effects

At high concentrations, ozone is a bluish gas with a characteristic pungent odour, often described as "smelling like" new mown hay or sparking electrical machinery. Ozone is found naturally in the atmosphere as a result of the action of solar radiation and electrical storms at the altitudes attained by modern aircraft and as a major constituent of photochemical smog. The characteristic odour is readily detectable at low concentrations (10-50 ppb)(1).

Acutely, ozone is a highly injurious gas at relatively low concentrations. It has been reported that irritation may occur at a concentration as low as 0.1 ppm, although some subjects reported no symptoms after 2-5 hours of exposure to 0.5 ppm. The primary site of acute injury is the lung which is characterized by pulmonary congestion, edema and hemorrhage. As well as the pulmonary effects ozone is reported to have caused a sensation of irritation to the eyes within 6 minutes at a concentration of 2 - 3.7 ppm. Chronically, O_3 has been reported to result in bronchiolitis and bronchitis in animals exposed daily to six hours for one year at concentrations slightly in excess of 1 ppm (2,3). The current US Occupational Safety and Health Administration Permissible Exposure Limit for ozone is 0.1 ppm averaged over an eight-hour work shift (3), with a Short Term Exposure Limit (STEL) of 0.3 ppm recommended (2).

The U.S. Federal Aviation Administration (FAA) has issued a standard on airplane cabin ozone contamination, which applies to flights of three or more hours, in the operation of large transport category airplanes by air carriers and commercial operators. The Time Weighted Average (TWA), FAA ozone standard for such flights is 0.1 ppmv, sea level equivalent (760 mmHg and 25°C). As of 20 February 1980, the ozone ceiling concentration at any point in the flights shall not exceed 0.25 ppmv, sea level equivalent (4).

In a recent review article, Melton has concluded that the evidence is clear that there is a threshold level for toxic manifestations of O_3 exposure, as well as threshold dose (5). Dose is defined as the product of ozone concentration and duration of exposure. Of these two determinants, ozone concentration is by far the most important. During actual flight, this will mean that peak concentrations are more important than the duration of exposure in assessing ozone-induced symptoms. For example, brief exposures to 1.0 ppmv may be more effective in causing "ozone sickness" than would a sustained exposure to 0.2 ppmv. Further the effects of exposures to 1.0 ppmv would not be reversed by subsequent flight segments when there was no O_3 present. Thus, a time weighted average (TWA) may not give an accurate index of exposure without due consideration being given to peak exposures.

METHODS

Ozone levels aboard the CC137 were measured using a Columbia Scientific Industries, Austin, Texas, CSI 2000, ozone meter. The measurement principle of the instrument is based on the gas-phase chemiluminescent reaction of ozone with ethylene. Atmospheric air reacts with the ethylene in a chamber containing a photomultiplier tube (PM). The intensity of the generated light, which is detected by the PM tube, is directly proportional to the ozone concentration in the air. The resulting electronic signal is displayed on a meter and the output voltage provided was used to drive an Esterline Line Angus portable strip chart recorder.

As CF regulations did not permit the transport of 100% ethylene gas, it was necessary to use 10% ethylene and 90% carbon dioxide. This "ethychem gas" mixture was considered safe for air transportation and was stored in a Type 4 high pressure cylinder. Thus the entire monitoring unit that was taken onboard the CC137 consisted of the CSI 2000 ozone meter, chart recorder and "ethychem gas" cylinders. The ozone meter and strip chart were both powered by internal batteries thus eliminating the need for an aircraft electrical supply.

CALIBRATION PROCEDURE

Ground Level

Ground level calibration consisted of introducing ozonated air from the Columbia Scientific Industries MEC1000 ozone generator into the CSI 2000 ozone meter, by means of the internal pump of the ozone meter. The O_3 output concentrations of the generator were established by a standard wet chemistry procedure, 1% neutral buffered potassium iodide (NBKI) (6). The NBKI values were found to be within

± 10% of the selected output of the CSI 1000 ozone generator. Four different settings on the O_3 generator were thus checked by this method. Prior to actual operation of the CSI 1000 ozone generator, the instrument was allowed a warm-up period of at least 24 hours. This allowed sufficient time to achieve a stable ozone output. Following several calibration checks it was noted that the calibration varied little from day-to-day; usually less than one percent.

Pre- and post-flight calibration was carried out at CFB Trenton and CFB Comox. On each occasion the CSI 1000 was allowed to warm-up for a minimum of a three-hour period. This calibration curve compared favourably with those previously obtained in the laboratory.

Simulated Altitude

As reported by Lurker (4) a correction factor should be established for proper operation of the ozone monitor at altitude (i.e., ideal gas law corrections are not considered adequate). The CC137 (Boeing 707) uses a pressurized system (approximately 8.75 psig pressure differential) to maintain an equivalent cabin altitude of 7000 feet. Therefore the CSI 2000 ozone meter must be calibrated at simulated altitude prior to actual inflight surveys.

To determine this correction factor several "flights" were made in the DCIEM Altitude Chamber to an altitude of 7000 feet (this corresponds to the cabin pressure of the Boeing 707 of 587 mmHg).

During this procedure the CSI 2000 ozone monitor was taken to altitude in the decompression chamber while the CSI 1000 ozone generator remained at ground level. These were connected, with the necessary plumbing, through sampling line connectors in the bulkhead of the chamber. The necessary flow adjustments were made externally on the ozone generator to take into account pressure and flow changes with increased altitude. The calibration curves established for both ground level and 7000 ft altitude are shown in Figure 8.

INFLIGHT MONITORING

On the day of departure from CFB Trenton the CSI 2000 ozone monitor underwent a calibration check at ambient pressure. Inflight monitoring took place on each of three flight route segments on both the westerly and easterly flights as illustrated in Figure 1. No monitoring was carried out on the Vancouver/Comox legs of the normal service flight as the maximum altitude attained was less than fifteen thousand feet. On each of the routes, separate ozone monitoring began when a stable flight level had been established and continued until the aircraft began descent for landing. The actual flight time for each segment is included in Table 1. All necessary data, such as

altitude, location and cabin pressure were obtained from the aircraft navigator and annotated on the strip-chart for later reference.

Continuous ozone monitoring was carried out in the approximate centre of the aircraft cabin, by securing the ozone monitor to the centre passenger seat. One four-foot long (1/4 inch diameter Teflon) sampling line was located at the approximate breathing zone level and in turn connected to the ozone monitor.

RESULTS AND DISCUSSION

The resulting ozone concentrations (corrected to ground level equivalent) obtained during the two days of this study are shown in Table 1. As well, these concentrations are graphically presented for each portion of the flight in Figures 2-7. From this table it can be seen that the maximum concentration was obtained on the Ottawa-Winnipeg segment of the flight on Day 1 of this study. This corrected value of 135 ppb is above the current Time Weighted Average (TWA) of 100 ppb, however, it is below the FAA recommended ceiling concentration of 250 ppb. The concentrations appearing in Table 1 have been corrected to Standard Temperature and Pressure using the Altitude Correction Factor of 1.73. This factor was obtained by calibrating the ozone monitor at a simulated altitude as previously described under the Methods Sections.

A comparison of the results obtained on the eastern flight with those of the western flight points out a considerable reduction in the ozone levels. This ranges from a maximum concentration of 135 ppb on the Ottawa to Winnipeg leg to a maximum concentration of 93 ppb on the easterly Winnipeg-Ottawa segment of the study. This may be explained by the fact that the eastern portions of the flight occured at a flight altitude two thousand feet below that of the western trip. As well, from the AES data presented in Table II, it can be seen that the concentration of ozone at 37,000 feet during a similar time period, is considerably less than that at 39,000 feet (1670 ppb vs 920 ppb).

The results of the cabin ozone measurements taken at 39,000 ft altitude in the region of Edmonton on 10 Feb 82 (Table I), indicated the maximum ozone concentration to be between 119-121 ppb. When compared to the ozone sounding atmospheric O_3 concentrations in this region at a similar altitude (1.67 ppm at 39,370 ft, Table II), it is evident that the engine turbo compressors (used to pressurize and heat the aircraft) are able to remove over 92% of the atmospheric ozone prior to its entry into the cabin.

CONCLUSION

The results of this single study of ozone measurements in a Boeing 707 (CC137) during a seasonal period of high atmospheric ozone indicated that the cabin ozone concentrations did not exceed the safe ocupational exposure limits for flight. The study further determined that the cabin pressurization system of the aircraft was effective in removing over 90% of the ozone present in ambient atmosphere prior to its entry into the cabin.

The findings of this study indicate that ancillary ozone removing equipment need not be added to the aircraft. The results obtained are further supported in that there has never been a reported incident of subjective effects which could have been due to ozone in the CC137 aircraft.

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ACKNOWLEDGEMENTS

The author wishes to acknowledge; the technical assistance provided by Master Corporal J.L. O'Neill and Corporal P. Yergeau of the Health Sciences Section, DCIEM, the support and hospitality demonstrated by the aircraft commander, Captain Joe Elliott, 437 Squadron, CFB Trenton, and his crew; and for the assistance of Dr. Wayne Evans of Atmospheric Environmental Services, Environment Canada, Toronto for the ozone data.

TABLE 1

CC137 (Boeing 707)
Ozone Results Obtained on a Domestic Across Canada Flight
9 Feb 1982 to 10 Feb 1982

FLIGHT SEGMENT ROUTE	TIME (EST)	ALTITUDE X 10^3 FT	FLIGHT SAMPLE TIME (MIN)	MAXIMUM CABIN CONCENTRATION PPBV*	CONCENTRATION PPBV* (GROUND LEVEL EQUIVALENT)
Ottawa-Winnipeg	1945 - 2207	39	77	78	135
Winnipeg-Edmonton	2254 - 0043	39	63	69	119
Edmonton-Vancouver	0123 - 0236	39	32	70	121
Vancouver-Edmonton	1813 - 1917	37	29	44	76
Edmonton-Winnipeg	2006 - 2131	37	43	61	106
Winnipeg-Ottawa	2211 - 2355	37	72	54	93

*parts per billion by volume

TABLE II

Ozone Sounding Data for Edmonton
10 February 1982 - Time 11 GMT

HEIGHT (KMS)	HEIGHT (FEET)	OZONE (PPM)	WIND DIRECTION (DEG)	WIND SPEED (M/S)
.8	2,625	.06	300	5
2.8	9,186	.07	315	18
3.3	10,827	.08	312	19
5.2	17,060	.09	300	25
6.8	22,310	.08	295	32
7.5	24,606	.12	297	37
7.9	25,191	.19	298	40
8.7	28,543	.19	300	46
9.0	29,528	.18	300	45
9.5	31,168	.39	300	42
10.3	33,793	.58	298	36
11.2	36,745	.92	295	29
11.8	38,714	1.25	298	27
12.0	39,370	1.67	299	26
12.4	40,682	1.51	302	25
12.8	41,995	.70	304	23
13.1	42,979	1.06	305	23
13.2	43,307	1.05	305	23
13.4	43,963	1.20	306	23
13.6	44,619	.75	306	23
13.8	45,276	.61	306	23
14.7	48,228	.95	308	22

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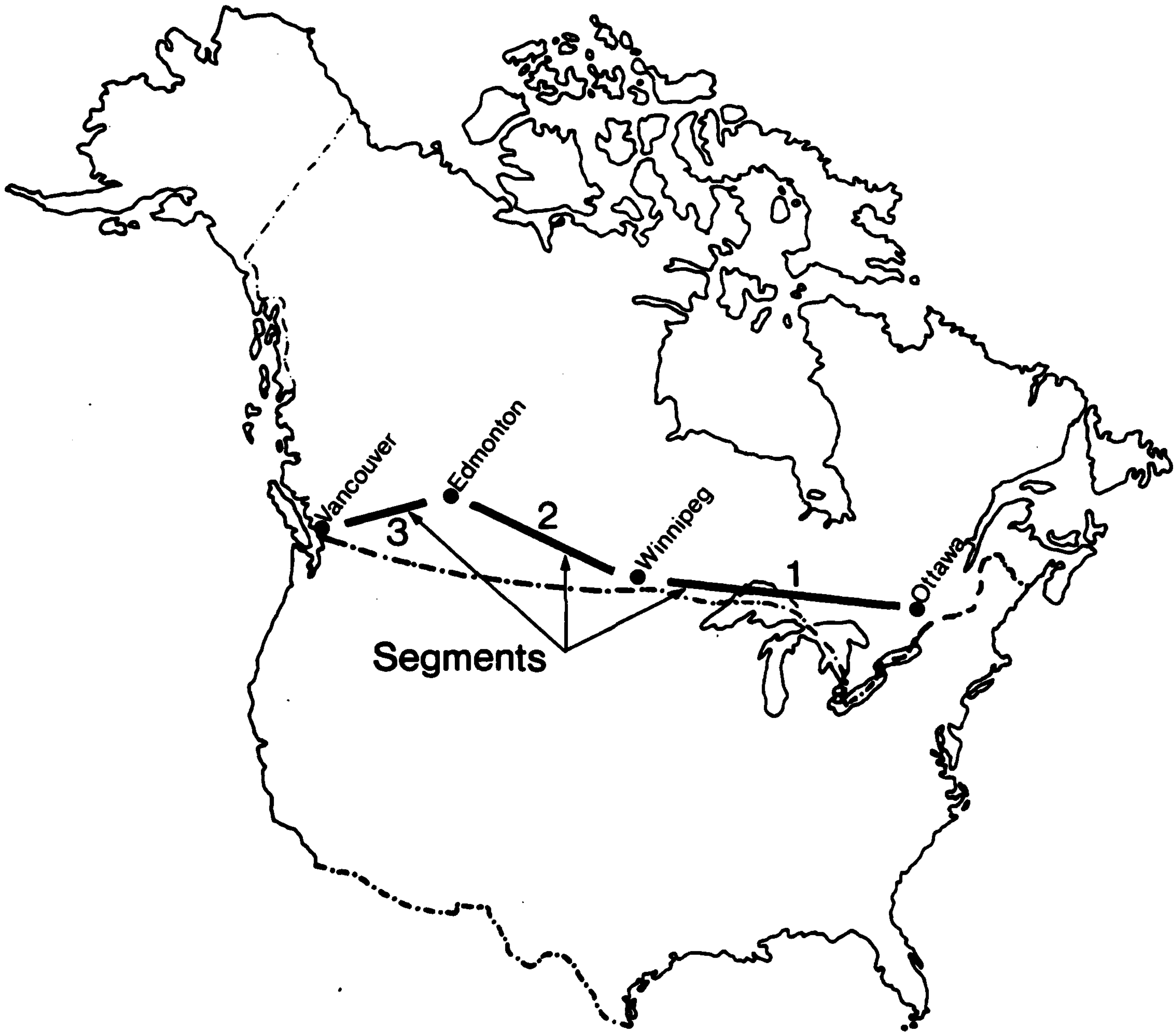


Figure 1

Sampling Segments for CC 137 (707)
Ozone Monitoring

GROUND EQUIVALENT CABIN OZONE CONCENTRATIONS IN CC137 (BOEING) AT 39,000 FT.

OTTAWA TO WINNIPEG

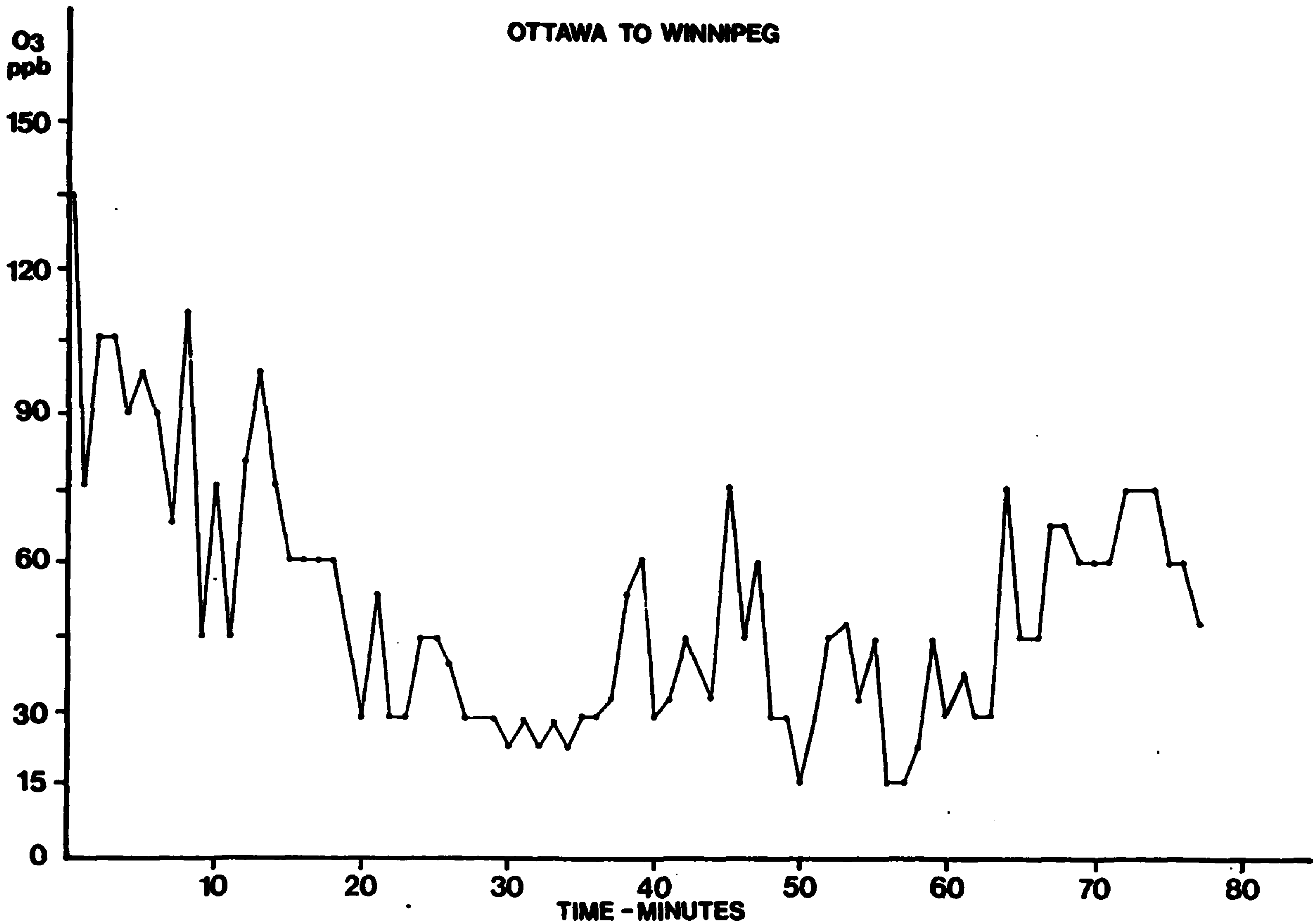


Figure 2

GROUND EQUIVALENT CABIN OZONE CONCENTRATIONS IN CC 137 (BOEING) AT 39,000 FT.

WINNIPEG TO EDMONTON

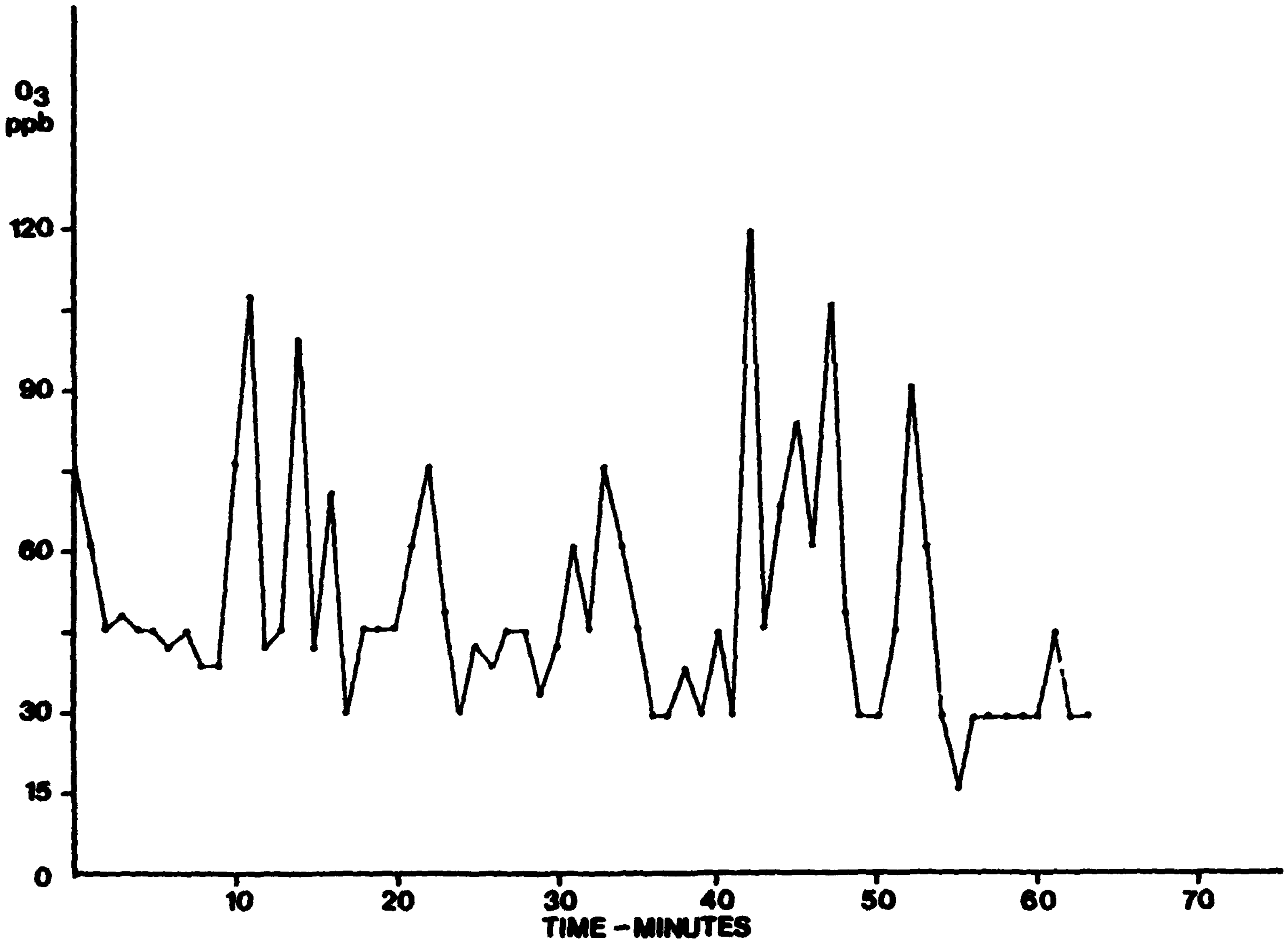
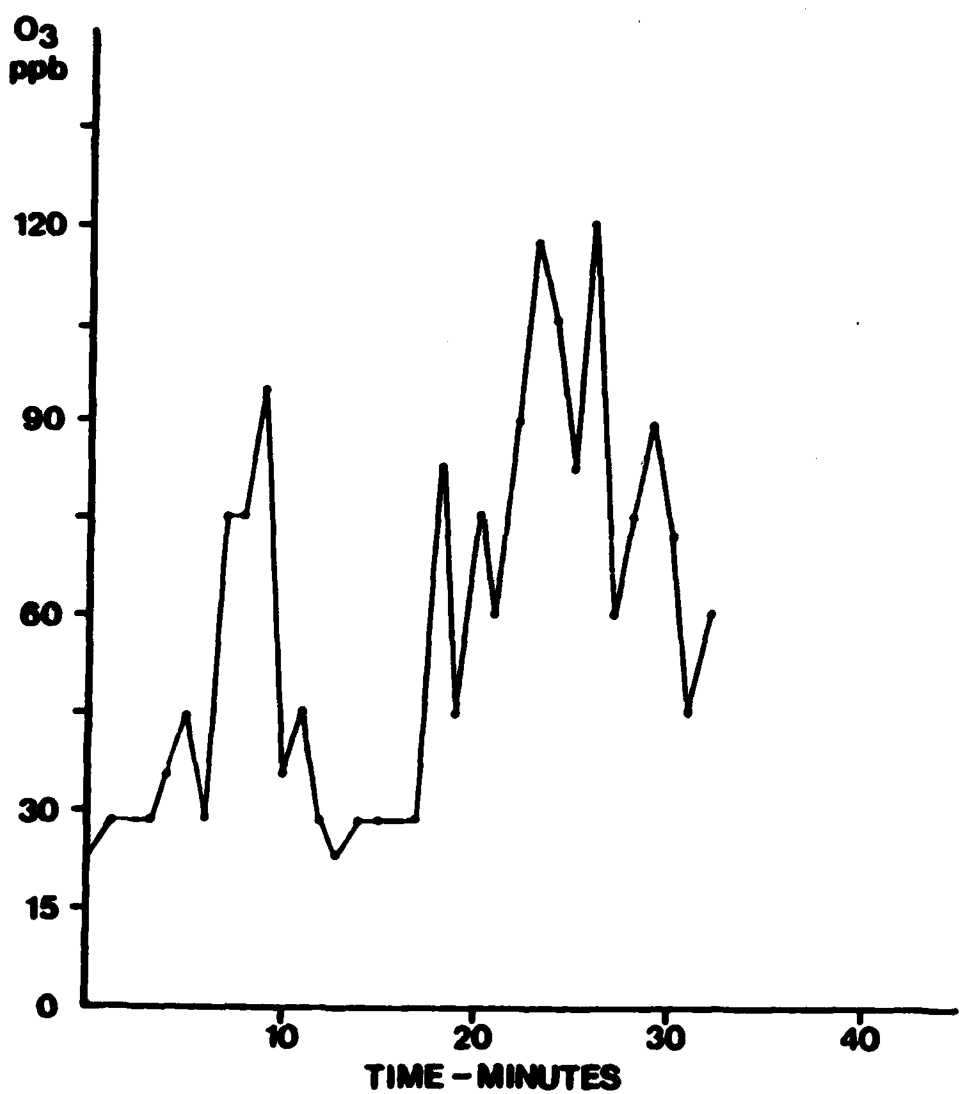


Figure 3

GROUND EQUIVALENT CABIN OZONE CONCENTRATIONS
IN CC 137 (BOEING) AT 39,000 FT.

EDMONTON TO VANCOUVER



GROUND EQUIVALENT CABIN OZONE CONCENTRATIONS
IN CC 137 (BOEING) AT 37,000 FT.

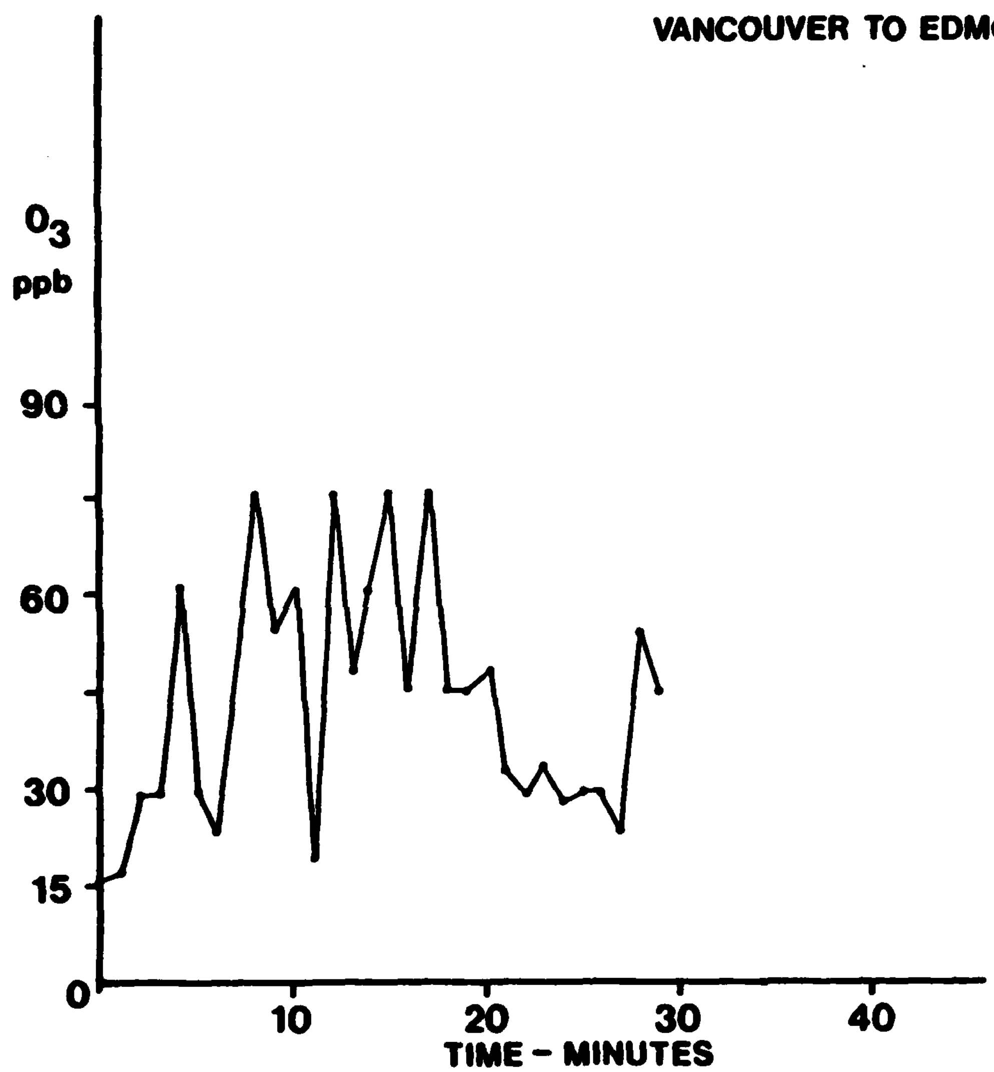


Figure 5

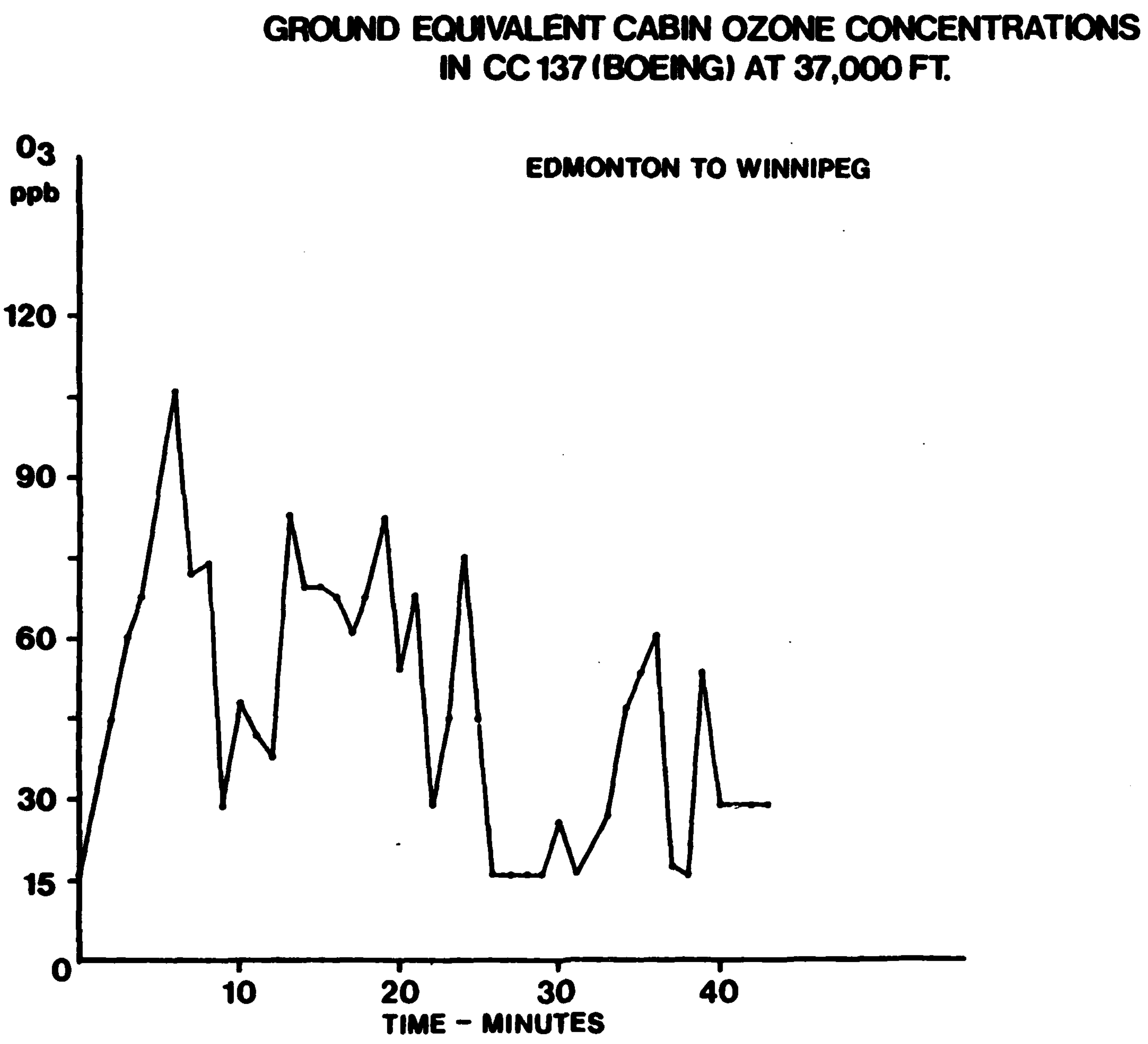

GROUND EQUIVALENT CABIN OZONE CONCENTRATIONS
IN CC 137 (BOEING) AT 37,000 FT.
EDMONTON TO WINNIPEG
O3
ppb
120
90
60
30
15
0
10
20
30
40
TIME – MINUTES

Figure 6

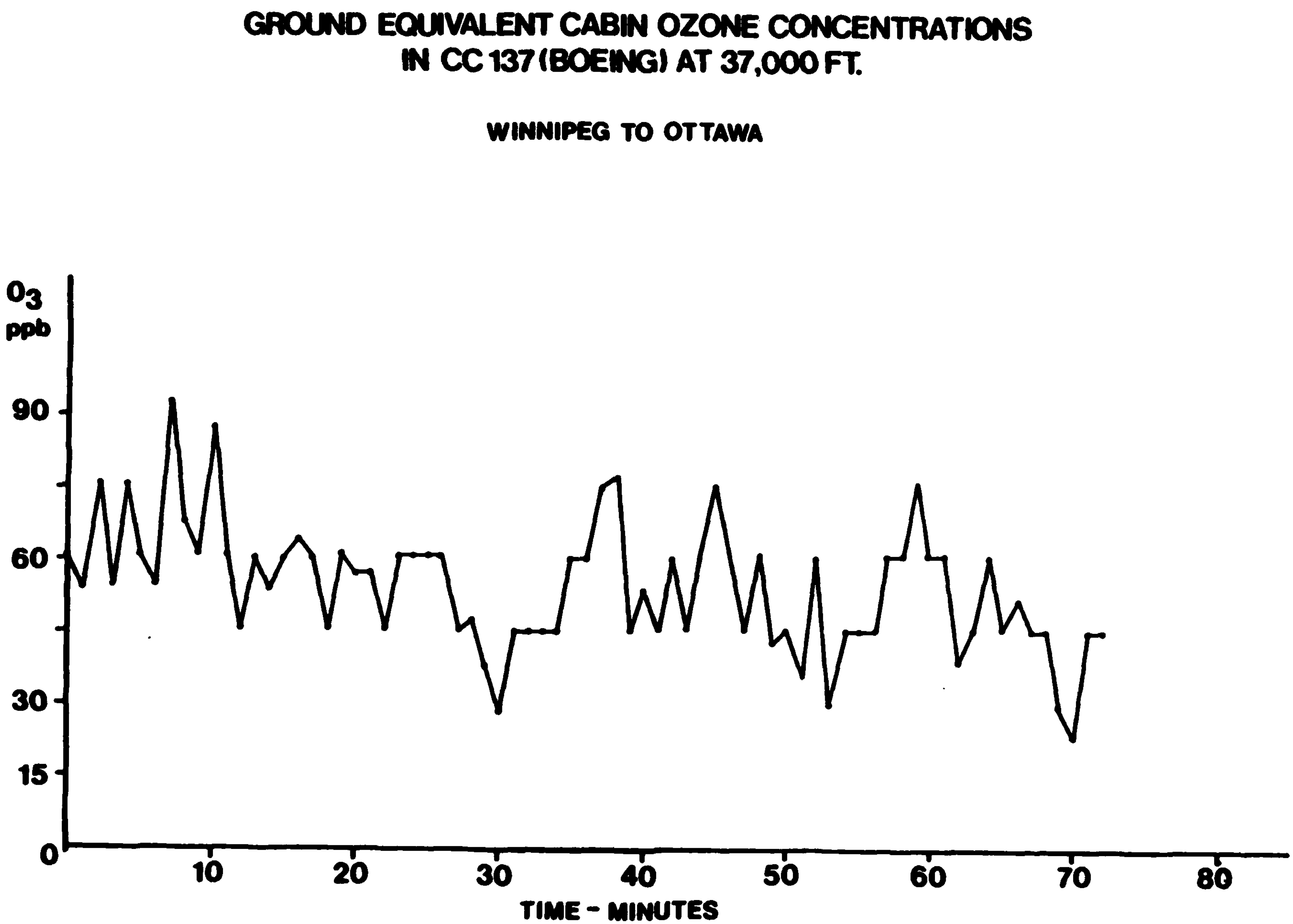

GROUND EQUIVALENT CABIN OZONE CONCENTRATIONS
IN CC 137 (BOEING) AT 37,000 FT.
WINNIPEG TO OTTAWA
O3
ppb
90
60
30
15
0
10
20
30
40
50
60
70
80
TIME - MINUTES

Figure 7

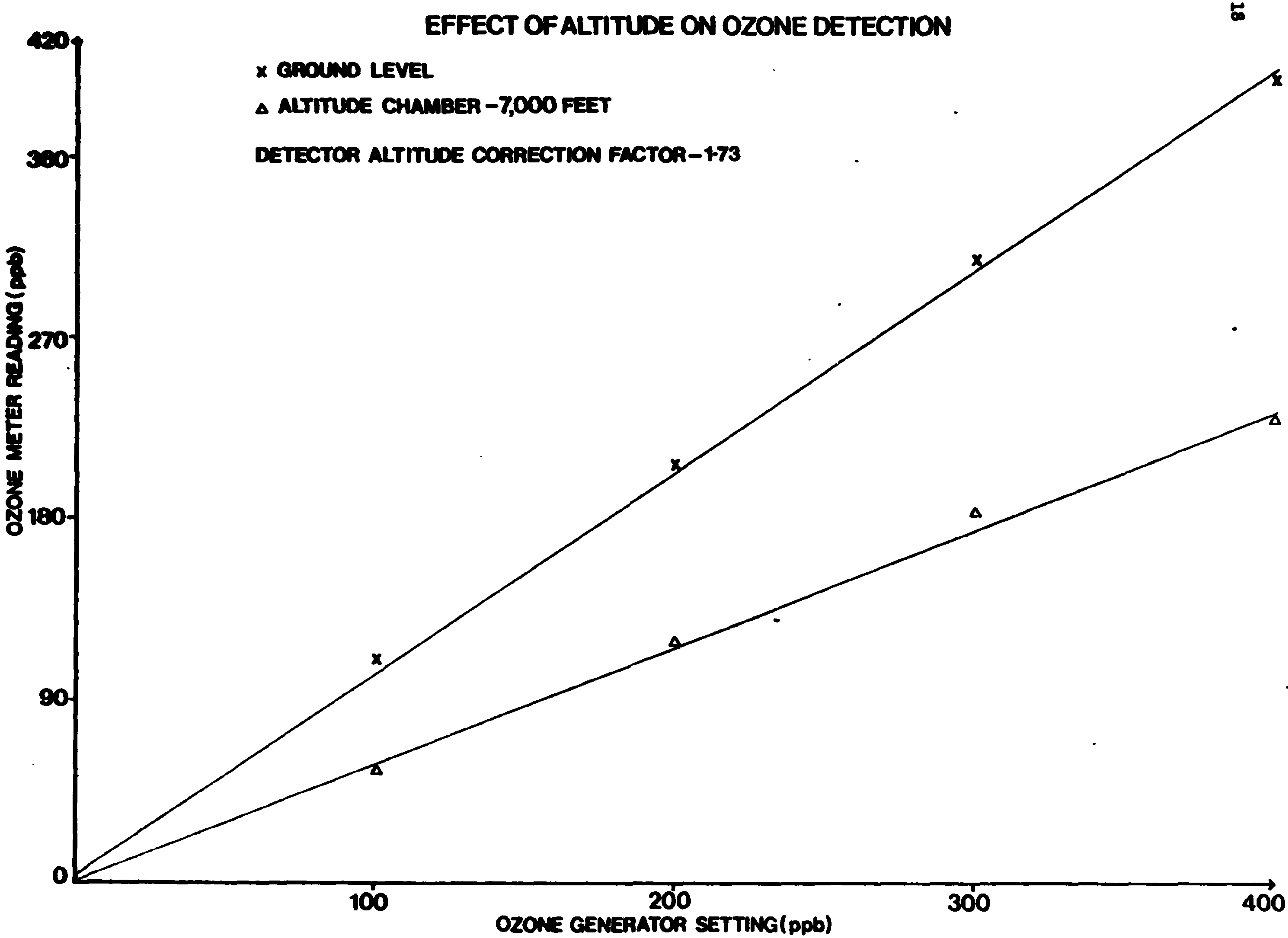

EFFECT OF ALTITUDE ON OZONE DETECTION
x GROUND LEVEL
△ ALTITUDE CHAMBER – 7,000 FEET
DETECTOR ALTITUDE CORRECTION FACTOR – 1·73
OZONE METER READING (ppb)
0
90
180
270
360
420
OZONE GENERATOR SETTING (ppb)
100
200
300
400

Figure 8